EPSC Abstracts
Vol. 11, EPSC2017-227, 2017
European Planetary Science Congress 2017

Occurrence of outgassed atmospheres on stagnant-lid Super-Earths

C. Dorn (1,2), L. Noack (3) and A. Rozel (2)
(1) University of Bern, Switzerland, (2) ETH Zurich, Switzerland, (3) Royal Observatory of Belgium in Brussels, Belgium

Abstract

We explore volcanic outgassing on stagnant-lid exoplanets of different interior structures and compositions. We study planets of 1–8 $M_\oplus$ (Earth masses) (Figure 1), that have refractory bulk abundances that are compatible with abundance proxies of planet-hosting stars (i.e., Mg/Si, Fe/Si). With a set of more than 1400 super-Earth cases, we study the influence of thermal, structural, and compositional parameters on volcanic outgassing. Besides thermal parameters, planetary mass crucially influences possible outgassing. At high masses (>6–7 Earth masses), the large pressure gradient in the lithosphere generally prohibits partial melting at depth. We also demonstrate how our findings provide interpretative means for the observational studies on exoplanet atmospheres.

1. Introduction

Our knowledge on the diversity of their interiors and atmospheres is limited, because exoplanet data are generally few and do allow for very different interior structures and compositions. The anticipated diversity of atmospheres on super-Earth exoplanets is subject to planet formation and evolution processes. Among the long-term processes, interior outgassing is relevant. Here, we study how outgassing on super-Earths scales for different interior structures and compositions.

2. Interior models

While accounting for high-precision astrophysical data and associated uncertainties (mass M, radius R, bulk abundances Mg/Si and Fe/Si) of super-Earths, we calculate for each synthetic planet the two endmember interiors that are those of maximum and minimum core size that fit data within the 1-σ uncertainty (σ_M = 10%, σ_R = 5%, $\sigma_{Fe/Si}$ = 20%, $\sigma_{Mg/Si}$ = 20%). More details in Dorn et al. (2015, A&A, 577, A83).

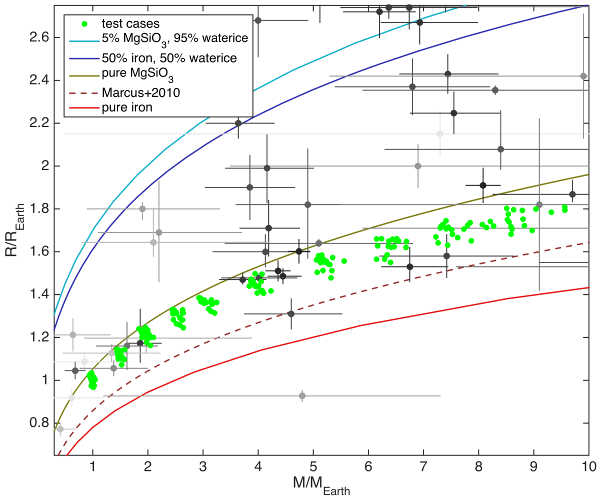

Figure 1: Masses & radii of considered planet cases (green dots) compared to mass-radius relationships of idealized compositions.

3. Convection model

We model convection in a compressible mantle in the 2-D spherical annulus geometry using the truncated anelastic liquid approximation. Reference profiles for temperature, density, gravity, and pressure, as well as material properties of thermal expansion coefficient, thermal heat capacity, and thermal conductivity are taken directly from the interior models (Section 2). Given these input profiles and imposed lateral variation fields for temperature, density, and pressure, the convection code solves the conservation equations for mass, momentum and energy.

3.1. Melting:

Varying mantle composition affect melting temperatures T_s, for which we derive an iron-dependent melting law for low pressures based on [1] and [2], where

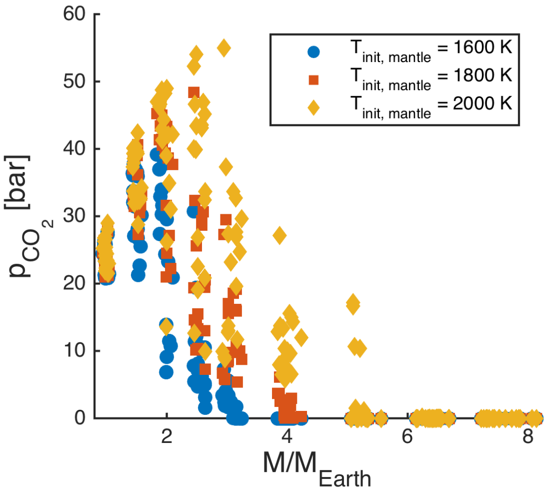

Figure 2: Influence of initial mantle temperature on outgassing. The amount of outgassing is in terms of partial pressure p_{CO_2} Surface temperature T_{surf} is fixed to 280 K in all test cases.

$\mathcal{X}_{Fe}$ is in wt%.

$$\begin{array}{rl} \Delta_{T_s} = & (1.02 + 0.641P - 0.0362P^2) \\ & \cdot(10 - \mathcal{X}_{Fe}), \textbf{ if P}\leq\textbf{12 GPa} \\ \Delta_{T_s} = & 3.6\cdot(10 - \mathcal{X}_{Fe}), \textbf{ else.} \end{array} \quad (1)$$

4. Results and Conclusions

We find that planet mass has a first order effect on outgassing. Above ~ 7 $M_\oplus$, outgassing becomes negligible in all test cases (note T_{surf} = 280 K). Thermal parameters are of primary importance, since they extent the range of planet masses, where outgassing is observed (Figure 2). Variation of core sizes and mantle compositions seem to be of secondary influence on depletion and outgassing (Figure 3). Finally, secondary atmospheres on stagnant-lid planets only occur in a limited range of planet masses. The identification of secondary atmospheres beyond that limit implies different dynamic regimes (e.g., mobile lid). We propose a qualitative comparison of our findings with actual gained insights on the atmosphere types of observed exoplanets.

This analysis will inform the interpretation of determined thicknesses and compositions of exoplanet atmospheres, e.g. from future spectroscopic observations (e.g., E-ELT, JWST).

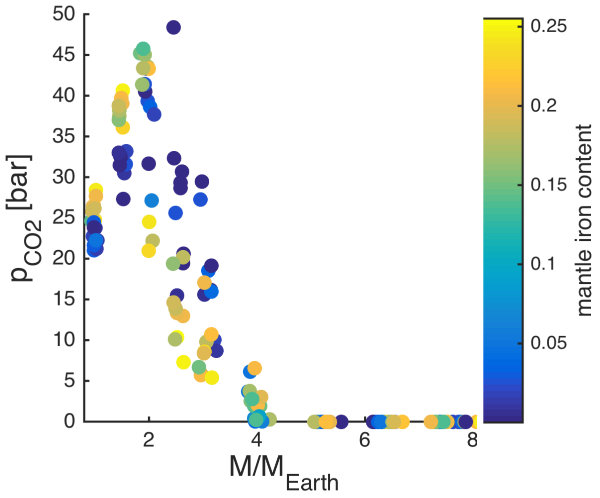

Figure 3: Influence of mantle iron content on depletion and outgassing for different planet masses and bulk compositions (Fe/Si$\in\{.5, 1., 1.5\}$ Fe/Si$_{Sun}$ and Mg/Si $\in\{.5, 1., 1.5\}$ Mg/Si$_{Sun}$).

Acknowledgements

This work was supported by the Swiss National Foundation under grant 15-144 and is MERAC-funded by Swiss Society of Astrophysics and Astronomy. It was in part carried out within the frame of the National Centre for Competence in Research PlanetS. L. Noack has been funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office through the Planet Topers alliance.

References

[1] Kiefer et al. (2015), Geochimica et Cosmochimica Acta, 162, 247–258

[2] Hirschmann, M. M. (2000), Geochemistry Geophysics Geosystems, 1–26.